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Characteristics of Hemi Savonius Windmill with Multi-Level Blades as a Model of Energy Conversion Systems for Windmill Techno Park on the Coastal Areas

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--***ABSTRACT***--
The purpose of this study was to obtain a design of the Hemi Savonius windmill model that is related to construction information, functions and characteristics as a wind energy conversion system. The design results are used to complement the windmill techno park facilities in the context of developing integrated tourism education. The construction of the energy conversion system is a modification of the basic model of the Savonius windmill rotor, which consists of two rotors with 6 (six) leaf blades, which are arranged in a multilevel opposite or referred to as a Multilevel Blades Hemi Savonius Windmill model. The rotor blades are planned by splitting into two parts, the same as the Savonius ferrite rotor blades. The test results on the model were carried out in the Laboratory, while the prototypes in the field, which showed the performance of the windmill, were quite reliable as wind energy conversion systems. Through the results of data analysis, it is known that the ability of this wheel to extract kinetic energy at an average velocity of V = 2.8 m/sec achieves rotor efficiency of 51.4% with a rotation of 34.6 rpm and electrical voltage at a 15.2 Volt generator. In addition, the construction of the physical construction of the rotor and its installation on the pillar of the support tower in the field along with the arrangement of a number of other windmill models, the Hemi Savonius windmill can serve as an information & communication medium to be used as a reference for learning resources and tourist attractions.
KEYWORDS: *Windmill Characteristics, Hemi Savonius Windmill Model, Windmill Techno Park*

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I. INTRODUCTION

In terms of functional aspects as an energy conversion system, windmills/wind turbines are machines or equipment used to transform kinetic energy or wind motion into mechanical and electrical power through rotational motion of the rotor & transmission shaft. The rotor and shaft rotation is planned to produce revolutionary (torsion) energy that requires the shape and size and arrangement & installation of certain blades to obtain a more effective and efficient value /amount of conversion power. Based on the form and arrangement of the shaft of the energy conversion system, today many models of windmills (wind turbines) have been developed with various rotor and drive blades. In general the types can be classified as windmills with vertical and horizontal construction [1]. While in terms of aerodynamic aspects of the rotor / blade, the windmill is divided into 2 (two) principles, namely windmills extracting wind kinetic energy using only the drift force of wind flow or by the principle of utilizing the lift force produced by wind flow through propyl/aerodynamic shape of the blade[2].

Especially for vertical windmills, the Savonius rotor model from the beginning of its history of creation by Sigurd J. Savonius in 1931 has been carried out many modifications to the construction of the blade. The recent development of the Savonius windmill model was designed and introduced by Asgeirsson, S (in Sweden) with blades profile the curved are given a test-shaped aesthetic on the lip/sides of the blade[3]. The Savonius Helix windmill blade with the rotor section has a linear trailing edge allowing the blade to provide a rotational force and create a vertical vortex of air, as shown in Fig. 1 [4].

As for this Hemi-Savonius windmill model the profile of the blade is designed & adopted rather resembling the construction of one of the windmills (Fig. 1), with the arrangement of the blades in a multilevel and opposite manner. The rationale for the design is to divide into two sections of the Savonius windmill profile, so that the rotor blades become 1/2 the size of Savonius windmill/cylindrical hemispheres. However, in this case what needs to be addressed technically is however the type (profile) of construction and arrangement of blades of a windmill is developed, it is almost certain that each model of windmill rotor will have certain characteristics in the ability to convert wind energy.

In this regard, the problem raised in this study is how to look at the physical profile and the modification of the modified Savonius hemi-windmill performance in converting wind motion kinetic energy into shaft power and electricity. In addition, how to build and develop a hemi windmill model Savonius is related to tourism development, especially education tourism (edutourism) through the introduction of Windmill Techno Park (WTP) in the coastal area[5]

a. Rotor of Aesthetic Curve Savonius b. Rotorof HelixSavonius

Fig. 1.Development of the Savonius Rotor Models

II. BASIC PRINCIPLES AND CONSTRUCTION OF SAVONIUS WINDMILL

Basic Principles of Savonius Rotor

The Savonius model vertical turbine with a vertical axis (Vertical Ax Wind Turbine = VAWT), created for the first time by Sigur J Savonius in 1922. Rotor savonius requires less wind thrust compared to horizontal shaft windmill models (Horizontal Axle Wind Turbine = HAWT). This is because vertical shaft windmills only use the drift force to rotate the rotor shaft, and in addition it also has a lighter rotor weight compared to each unit of power produced. That is, the Savonius rotor vertical shaft windmill has a smaller specific power (specific power). In addition, the rotor savonius is only suitable for use in design conditions / prerequisites that do not require large amounts of power. In addition, the design of Savonius windmills is so simple that it is easier to technically manufacture [6]. A simple savonius rotor can be made by utilizing and splitting two cans / oil drums and mounted in reverse, then connecting them with welding so that the two pieces form a cross section of the curve as shown in Fig 2.

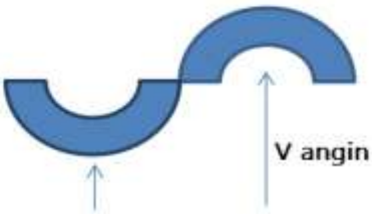


Fig. 2.Rotor of Savonius

In its development the basic construction model of the Savonius windmill design can be classified into (a) the rotor type resembling the "U" shaped curve obtained through the arrangement of two arches / plates in opposite (b) the rotor type resembling the letter "S" which obtained through the arrangement of two pieces of plate / plate by shifting the position of the rotor bowls, and (c) the type of rotor with propyl bowls/shapes in the shape of the letter "L". Some of the Savonius rotor variations shown in Fig 3, all of which work well. Savonius efficiency is only around 15 percent but they are ideal for many situations[7].

a.Type" U" b. Type "S" c. Type "L"

Fig 3. Types of Savonius Windmill Blades

Especially for S and L type rotors besides the process is relatively easy with a simple technology, each rotor bowl can be installed eccentrically or made a little shift (offset) from the rotating shaft so that the flow of the wind flow freely crosses between the slits of the bowl rotor with its axis, as shown in Fig 4.

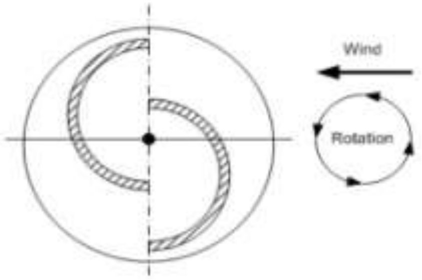


Fig.4. Wind Direction on Savonius Type S Rotor Turn

Wind flow through the rotor-shaft gap will affect the performance/operational characteristics of the windmill[8]. A study shows that to compare the performance of a windmill is through the gap coefficient/overlap of the rotor blades so that the ideal value is obtained at 0.242. The results of the study also stated that the value would not be optimal when each of his lips was connected to each other without gaps. However, the rotor with the U-type Savonius principle is very strong because the rotor blades are centered in the center of the shaft/stem, but are less efficient than the other Savonius types. While Savonius S type rotors are also very simple and can be designed easily, for example, made from a used drum. This type of Savonius design is slightly more efficient than the U type Savonius rotor, because some air flow will be deflected by both blades, then exit on one side of the other. While for the Savonius L type rotor is the most efficient design of other rotor forms. This type L Savonius windmill does not only have the advantage of the air being deflected to twice the flow of the current. In addition, a portion of the blades act like an airfoil when the wind current is at the edge, making the lift effect smaller and increasing efficiency [7].

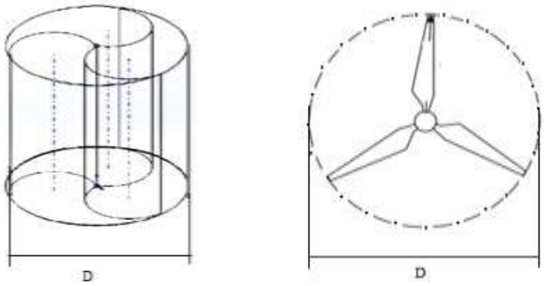
The rotor is a component of a windmill consisting of a shaft and blades that rotate/move when operating. Its function is as a container to extract the kinetic energy of wind into mechanical energy rotating the shaft. The dimensions of the rotor will determine the output of the power produced, which can be determined based on the equation as follows [9],[10].

$$D = \sqrt[5]{P\left[\frac{47\,\lambda}{n}\right]^{3}} \text{ or } \qquad D = \sqrt{\frac{P}{\frac{\pi}{8}\,\rho\, V^3 \eta}} \quad .... \quad (1)$$

where,

D = rotor diameter (m); P = desired power output (Watt); λ = tip speed ratio;V = Average wind speed (m/sec);η = windmill efficiency; ρ = air / wind density (kg/m^3)

In the planning analysis process, it should be noted the statement for rotor diameter, which depends on the type of windmill planned, whether the construction is in the form of horizontal or vertical windmills. For horizontal windmill diameter dimensions used in planning are seen & determined from the direction of projection of the front/rear view of the rotor, while for the type of vertical windmill the diameter size is seen from the direction the view appears above / below the rotor as shown in Fig 4.



a.Vertical Mill Diameter b. Horizontal Mill Diameter

Fig 4. Diameter Dimensions for Windmill Rotor

Performance of the Savonius Windmill

A number of results of research conducted by researchers indicate that Savonius windmills in operation only require the force of drag of the wind that works on the blade in order to produce a rotational speed of the rotor shaft. The number of torque produced or worked on the shaft is obtained through the thrust acting at the midpoint of the blade towards the radius/rotor arm. The thrust forces acting on Savonius windmill spoons are calculated based on the formula [11] as follows,

$$F = \tfrac{1}{2} \; C_p \, \rho \; A \; V^2 \qquad \text{..................} \quad (2)$$

where, ρ is known as wind density and A is the area of the blade sweep, while V is the wind speed, and Cp the power coefficient.

Usually this power coefficient is influenced & distinguished on the factor, the drag coefficient and the lift coefficient (lift) on the surface of the windmill rotor blades. In Savonius rotor type only has a drag force, where for the surface of the concave semicircle blade some results of the study obtained the value of drag coefficient Cd = 2.3, and for convex semicircle large the drag coefficient is obtained Cd = 1.2 [9]

Apart from the physical energy factor (P) and wind speed (V) and rotor diameter size (D) which are the main considerations in the early stages of planning, it should also be noted and taken into consideration that the larger the diameter of the rotor, the minimum wind speed needed to rotate the rotor will be smaller. In addition, the determination of the number of rotor blades according to the type of windmill will also have a relationship with the ratio of the speed of the blade tip to the shaft rotation speed which is referred to as the speed ratio tip factor. The large number of blades will result in a small tip speed ratio, while the smaller number of blades will result in a relatively large tip speed ratio. The value of this tip speed ratio can be determined using the following equation,

$$\lambda = \frac{\pi \; D \; n}{60 \; V} \qquad \text{..................} \quad (3)$$

where,
D = windmill rotor diameter (m); n = windmill rotor rotation; (rpm);V = wind speed (m / sec).

Graphically the relationship between the variation in the value of the tip speed ratio to the coefficient of power for various types of windmill rotors will vary as shown in the Fig5.

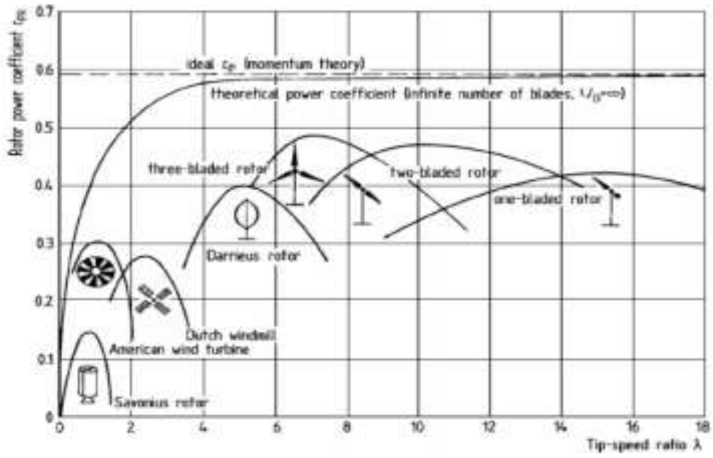


Fig 5. Graph of the Relationship between the Power vs. Tip Speed Ratio

Whereas, numerically the Cp power coefficient can be calculated through a comparison between the actual power (P_{act}) generated against the theoretical power (P_{theo}), namely:

$$Cp = \frac{P_{act}}{P_{theo}} \qquad \text{..................} \quad (4)$$

where the theoretical power, as previously described, depends on the kinetic energy of the wind speed and the area of the surface area of the blade planned so that,

$$P_{theo} = \tfrac{1}{2} \; \rho \, .A \, . \; V^3 \qquad \text{..................} \quad (5)$$

While the amount of actual power, can be known through the relationship between the magnitude of the moment torque and shaft rotation or the speed of the windmill rotor angle, namely;

$$P_{akt} = T \; . \; \omega \qquad \text{..................} \quad (6)$$

with a Torque value on the rotor shaft,

$$T = F.\, R \text{ and } \quad \omega = (2\,\pi\, n) / 60 \qquad \text{..................} \quad (7)$$

where:
T = Torque of rotor shaft (N m);F = force on the edge of the rotor blade (N); R = wheel rotors radius;ω = angular velocity of rotor (rad/det); n = windmill rotor rotation (rpm).

III. RESEARCHMETHODS

As for the construction aspects of this modified hemi savonius mills, the rotor blade size was made in halffrom the size of the area of the curvature of the Savonius windmill. The rotor is designed with a multi-level blade so that it is named a multi-level hemi-savonius windmill (Hemi-Savonius with Blade Stages Windmill). The position of the blade installation is also distinguished from the design results of the Assgeirson model as shown in Fig 6.

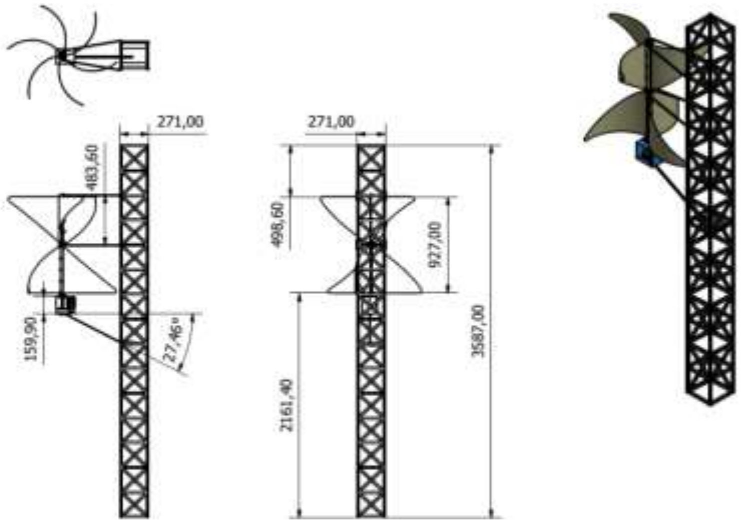
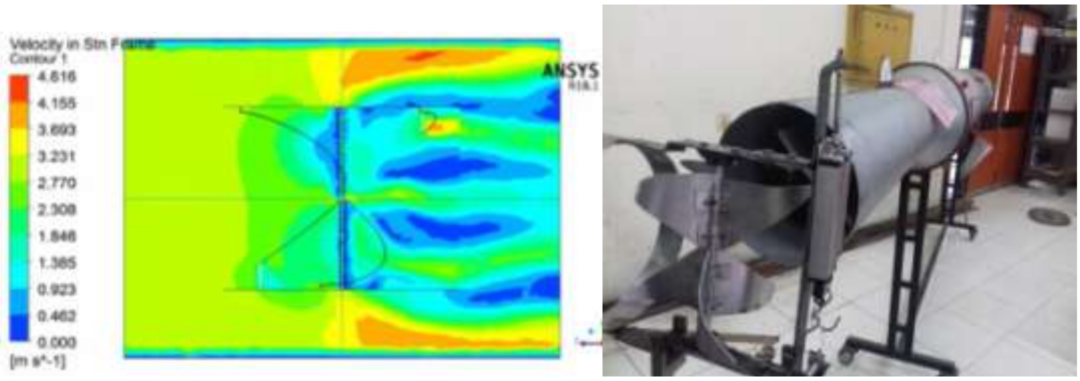


Fig 6. Hemi Savonius Windmill Designing Model

Designing a HemiSavonius windmill model in terms of its function is planned for a small-scale (25 Watt) wind energy to electric energy conversion system through a small generator placed & mounted on the bottom of the windmill rotor. The results of the design of the blade profile are then engineered into a rotor by arranging each blade in stages and the tops are opposite as shown by the construction results in Fig 7. Then, the application of the design results in the field is mounted on a pole made of galvanized water pipe which is adjusted to the conditions of the location on the edge of the beach, vulnerable to seawater corrosion.

a Prototype of the Results of the Design b Installation of the Mill in the Field
Fig 7. Results of Designing Windmill Hemi-Savonius Multi-Level Blade

To get an overview of the characteristics of the Hemi Savonius windmill, testing was carried out through a model scale approach in the Laboratory by making a dimension of 1:5 scale on the prototype to be installed in the field. The characteristics investigated consisted of the ability to extract wind energy, rotation, and energy produced by the rotor and efficiency. For this reason, before a field trial is carried out, a laboratory scale model is planned and carried out through the wind tunnel and simulating for the prototype by Ansys program as shown in Fig 8. The laboratory scale test results are then analyzed using formulations related to the characteristics of the Hemi Savonius windmill, i.e.



a. Prototype Simulating by Ansys Program b. Modelling Testing in Wind Tunnel

Fig 8. Wind Tunnel and Ansys Simulating for Model Characteristics Test

Push Force of Wind

The thrust generated by the speed of the wind pounding the field of exposure (sweep) of the Savonius Hemi windmill blades is developed from the principle of the impact force (momentum event). For the basic theory of the Savonius windmill model in fact only the drag force works at the midpoint of the same bowl, which is calculated through equation (7). Assuming the area of exposure for the Hemi savonius windmill is half of the Savonius rotor exposure area, the thrust force is calculated based on the formula with the modified equation as follows:

$F_{theo,\mathbf{HS}} = ½ \; [\; ½ \; . \rho . A . V^2 \;]$

$= ¼ \mathbf{[} \; \rho . A . V^2 \; \mathbf{]}$ .... (8)

In this plan the rotor spheres are made in stages (j) with the value of Cp energy coefficients taken through the graphs in figure 7, so that the propulsion formula for the hemi-savonius windmill is the ladder,

$F_{act,HS} = ¼ \; [\, C_p . \; \rho . A . V^2 \,] .j$ .... (9)

Torque and Axis Power Produced

By modifying it, then for this Savonius hemi windmill the torque that works the rotor shaft is,

$T_{act,\mathbf{HS}} = Fact,_{\mathbf{HS}} \; \mathbf{.} \; R .$ .... (10)

so that the power that works on the rotor output shaft is,

$P_{act,HS} = ¼ \; [C_p \rho \; A \; V^3] \; R . \omega .j$ .... (11)

Furthermore, the actual power of this rotor shaft (mechanical power) is converted into electric power through a generator at each change in speed / wind speed, that is,

$P_{actt,\, HS} = V . I$ .... (12)

where,

V = voltage generated (volts); I = Current strength issued (Ampere)

Windmill Efficiency

The efficiency of windmills is in the form of a comparison between the power that can be generated against theoretical power (input) from the aspect of the magnitude of the speed of the whirlwind that hits the windmill blades,

$\eta = \frac{P_{output}}{P_{input}} \times 100\% \text{atau} \eta = \frac{P_{akt}}{P_{teori}} \times 100\%$ .... (13)

IV. RESULT AND DISCUSSIONS

Result of Measurement and Characteristic Analysis

Based on the developed model laboratory tests were conducted using the Wind Tunnel test, with a scale of rotor blade radius (Rb) = 11.0 cm, rotor blade height (Lb) = 9.0 cm. In scale models testing in windmills is not equipped with electric generators. where the shaft power produced is measured based on the Prony brake System and the thrust force is obtained and analyzed based on equations (11) and (12) and (13) where the results are shown in Table 1.

Table 1. Measuring Performance of Hemi-Savonius Windmill Model

No	Wind Speed (m/sec)	Rotor Rotate (rpm)	Force (N)	Power *) [P_{act}/P_{theo}] (Watt)
1	1,6	10,0	1,20	0,023 /0,0264
2	2,5	27,1	1,30	0,094 /0,1101
3	3,2	35,2	1,48	0,194 /0,2114
4	4,0	42,7*	1,55	0,353 /0,4128
5	4,7	50,0*	1,65	0,463 /0,6696
Average	3,2	33,0	1,44	0,547/ 1,0240

Notes: R_b = 11,0 cm ;L_b = 90, 0 cm ; r_p = 1,0 cm *) Result of Analysis

When controlled by using these equations, to scale the model by giving several treatments to the wind tunnel, for an average wind speed of 3.2 m / sec, the average rotor rotation is obtained 33.0 rpm with an average braking force 0.44 N. Through analysis with equations (8, 10 and 13) for the average test results obtained the ability of the rotor to transform kinetic energy into power on the shaft, and efficiency as follows, (sampling calculating for average data):

$$P_{act,HS} = T \times \omega \quad \text{---------------------} \quad \omega = \frac{2\,\pi\,n}{60}$$

$$= F\,.R_b\ [\frac{2\,\pi\,n}{60}]$$

$$= 1,44\ .\ 0,11\ .[\frac{2\ .\ 3,14\ .\ 33}{60}]$$

$$= 0,547 \text{ Watt}$$

Whereas in theory,

$$P_{theo,HS} = \tfrac{1}{4}\ [\rho\ A\ V^3]\ .\ j \quad \text{-------} \quad \mathbf{A} = 1/4\pi\ D\ L = \tfrac{1}{4}\ .3,14.\ 0,22\ .\ 0,90 = 0,16\ m^2$$

$$= \tfrac{1}{4}\ [\,1,25\ .\ 0,16\ .\ (3,2)^3\ ]\ .\ 2$$

$$= 1,024 \text{ Watt}$$

with the level of rotor efficiency,

$$\eta = \frac{P_{act}}{P_{theo}} = \frac{0,547}{1,024} \times 100\% = 53,42\ \%$$

To get more concrete information about the performance of the Savonius Hemi windmill, then test in the field (Areas of the Windmills Techno Park). At a windmill a small scale generator is installed, so that the voltage and power generated can be measured, where data & analysis are complete like Table 2.

Table 2. Data on Field Hemi-Savonius Wind Test Performance Data

No	Velocityof wind in Coastal (m/det)	Turn of Windmill (rpm)	Current (I) (Ampere)	Voltage (Volt)	Power(Watt) [P_{act}/P_{theo}]*)
1	1,5	23,0	0,09	10,0	0,20 / 0,74
2	2,0	30,0	0,10	13,0	0,48 / 1,75
3	3,0	35,0	0,13	15,0	1,95 / 5,91
4	3,5	40,0	0,20	18,0	3,20 / 9.38
5	4,0	45,0	0,30	20,0	6,00/14,00
Average	2,8	34,6	0,16	15,2	2,43/4,802

Notes: R_b= 55,0 cm ; h_b = 2 x 45,0 cm, *) Result of Analysis

Through the results of the performance tests in the field and the analysis carried out obtained information on the characteristics of engineered windmills shows an average rotor power of 4.8 Watt with efficiency η = 51.4% at an average wind speed of V = 2.8 m / sec with an average shaft speed of 34.6 rpm and an average voltage of 15.2 volts. The result of the design of the Hemi Savonius windmill prototype was able to convert mechanical energy into generator power by an average of 2.43 Watts. The low efficiency and electricity produced are influenced by low generator efficiency.

V. CONCLUSION

Based on the results of the performance test and the analysis carried out it can be concluded some results of the study,

1. The technology of wind power conversion systems with Savonius windmill base models can be developed and modified with various various physical forms of blade construction. One of them is a model that is shown as the name as a multi-leveled Hemi Savonius Windmill.
2. Test results on a laboratory scale show that the savonius hemi windmill can work with quite good performance with the power generated at an average wind speed of 3.2 m/s of 0.547 Watts, with the physical size of model scale construction with diameter/radius 0,11 m.

3. Application of model prototypes in the field by making a larger physical construction size (around a ratio of 1: 5) shows almost the same performance (relatively good), and prospective to be developed / mass production as one of the tools for future wind energy conversion systems with efficiency the rotor is around 51.4% and produces a rotor of 36.4 rpm at a wind speed of 2.8m/sec.
4. For increased efficiency, the selection of bearings is better/special and makes the rotor construction somewhat higher/oval.
5. Physical appearance in the field as a means of completing the techno park windmills provides tourist attraction, especially integrated tourism education. Through the form/profile of construction and operational performance, it provides a nuance of learning for students/students as well as park visitors in general

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